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The ITER Plasma Control System Simulation Platform

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HIGHLIGHTS

- A development and test environment called PCSSP has been constructed for the ITER PCS.
- A description of requirements and use cases, a final design and software architecture design, users guide, and a prototype implementation have been delivered.
- The prototype implementation was demonstrated at IO in December of 2013.
- PCSSP will be deployed for alpha testing to the IO, the development group, and selected other ITER partners upon completion of the next development phase.

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ABSTRACT

The Plasma Control System Simulation Platform (PCSSP) is a highly flexible, modular, time-dependent simulation environment developed primarily to support development of the ITER Plasma Control System (PCS). It has been under development since 2011 and is scheduled for first release to users in the ITER Organization (IO) and at selected additional sites in 2015. Modules presently implemented in PCSSP enable exploration of axisymmetric evolution and control, basic kinetic control, and tearing mode suppression. A basic capability for generation of control-relevant events is included, enabling study of exception handling in the PCS, continuous controllers, and PCS architecture. While the control design focus of PCSSP applications tends to require only a moderate level of accuracy and complexity in modules, more complex codes can be embedded or connected to access higher accuracy if needed. This paper describes the background and motivation for PCSSP, provides an overview of the capabilities, architecture, and features of PCSSP, and discusses details of the PCSSP vision and its intended goals and application. Completed work, including architectural design, prototype implementation, reference documents, and IO demonstration of PCSSP, is summarized and example use of PCSSP is illustrated. Near-term high-level objectives are summarized and include preparation for release of an “alpha” version of PCSSP and preparation for the next development phase. High-level objectives for future work are also discussed.
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1. Introduction

The high cost and limited number of discharges planned for ITER, as well as constraints imposed by its nuclear mission, imply both minimal time for scenario and control tuning and a greater level of confidence needed in discharge performance prior to execution. The use of simulation for control development and verification has been well-established in research and commercial applications to support both of these requirements. Several operating tokamaks have made significant use of simulation tools in the development of control algorithms or key components of plasma control systems themselves. The broad success of this approach, both commercially and in the fusion community (references in [1]), led to an IO-funded task to develop such a simulation tool, known as the Plasma Control System Simulation Platform (PCSSP), to aid in development and testing of the ITER Plasma Control System. The current scope of

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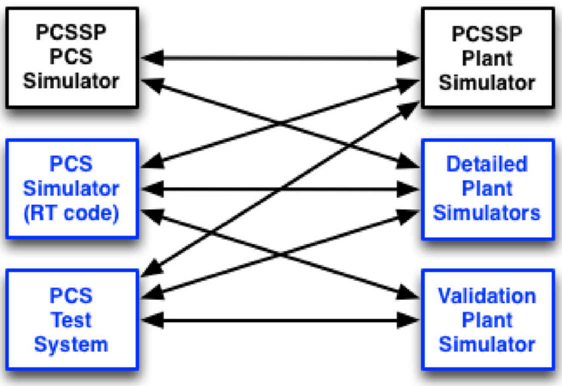

Fig. 1. Expected connections of PCS and plant simulators for closed-loop simulation. Blue blocks indicate objects external to PCSSP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

the project is limited to deployment of an initial version of the platform together with support tools and selected modules. It is envisioned that this version may be extended in subsequent efforts to provide a fully capable control simulation tool to also support ITER machine/system design and configuration evolution and discharge scenario development, and to support plant troubleshooting during operations.

2. Overview of PCSSP

The vision for PCSSP and high level use cases and requirements were summarized and a preliminary architecture description was provided in [1]. Briefly, PCSSP is envisioned as the simulation platform that will support the widely varying activities involved in developing the ITER PCS. These include initial exploratory simulations of proposed control algorithms through evaluation of candidate PCS architectural solutions, exception handling methods, policies, and architecture, methods for dealing with controller interactions, and candidate methods and architectures for control actuator management, to eventual automatic code generation for algorithm implementation in the operational PCS. To have value for control development, simulations must execute fast enough to support the commonly used develop/test iterative process. This implies an emphasis on plant system models that are simple but reasonably predictive, rather than the detailed models used for physics studies. PCSSP must also support validation of plasma and system models with data from existing tokamaks, to allow simulations used in PCS development to be usefully predictive.

There is an emphasis on rapid software prototyping during early development of new PCS algorithms, while later development requires formal change management. Both phases require flexibility and ease of use in constructing simulations from individual plant and PCS components. Variability in choices of components and detailed actions depends on the stage of PCS development (Fig. 1). The PCS function may be emulated by a simulated PCS in PCSSP, actual PCS realtime (RT) code running on simulation (non-realtime) computers, or PCS code running on PCS realtime hardware. Algorithm development can use the simplified PCSSP Plant, while more detailed testing and eventual validation of ITER pulse schedules require more accuracy.

Matlab/Simulink was selected as the base platform because it already satisfies many of the system requirements [2], which all reflect the fundamental objective of minimizing time, cost, and effort to develop the PCS architecture, algorithms, and control policies.

The goals of PCSSP are fundamentally concerned with simulation of interaction between the ITER plant and PCS, so the

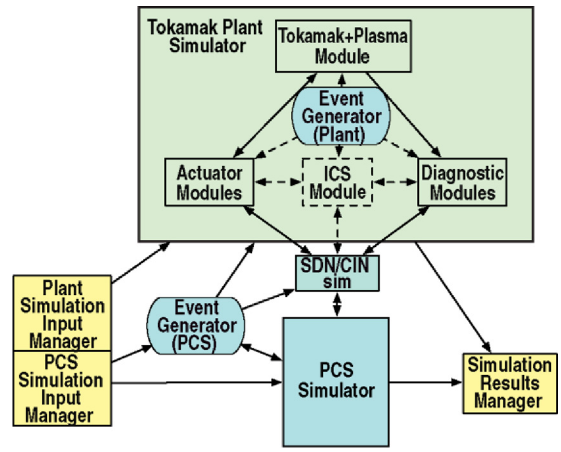

Fig. 2. PCSSP functional block diagram. Major components are plant simulator, PCS simulator, SIM, and SRM. PCS and plant simulators are in Simulink, but part or all of either block can be replaced by an external simulation or source of data to support use cases shown in Fig. 1. SIM and SRM execute in Matlab, outside of Simulink.

PCSSP must include those two main functional blocks (Fig. 2), input processes to manage inputs to the simulation [Simulation Input Managers (SIM)], an output process to archive and display results [Simulation Results Manager (SRM)], as well as the interfaces between them. Pulse schedule input is a distinct component within PCS SIM to enable replacement by the actual ITER pulse schedule when it becomes available. A functional block represented in Fig. 2 does not necessarily imply that all functions in that block are implemented as a single module.

In the plant, actuator modules simulate actuator responses to commands, diagnostic modules simulate processes involved in transforming physics quantities to real-time measurements, and the Tokamak + Plasma module simulates the combined plasma and device response to actuators. The SDN/CIN module simulates delays in moving measurement data from plant to PCS and commands from PCS to plant. SDN = Synchronous Databus Network (commands and diagnostic data) [5] and CIN = Central Interlock Network (machine protection control data). The Event Generator (EG) modules serve to trigger simulation of user-specified off-normal events.

The PCS simulator will contain multiple components, whose details will be defined during development of the PCS using PCSSP. However, it must include a set of control units, which receive input signals and produce output signals to perform specific functions such as feedback control, exception handling functions that detect and produce responses to any off-normal events that require triggering a change in control action [3], and a reference generator function to interpret the pulse schedule.

The Interlock Control System (ICS) module incorporates the Central Interlock System (CIS), an ITER overall protection circuit that responds to dangerous events [4], and Plant Interlock Systems (PIS), individual plant system (e.g. actuator/diagnostic) protection circuits.

3. Status of PCSSP development

As of the end of 2013, a description of requirements and use cases [2], a final design and software architecture design [6,7], users guide [8], and a prototype implementation have been delivered. This prototype was demonstrated at IO in December of 2013. The delivered PCSSP design, described here, varies somewhat from the preliminary description provided in [1]. Fig. 3 shows the Simulink model template provided with PCSSP, which users can modify to fit their application. The Plant represents models of the device and systems, the PCS represents the plasma control system for the device,

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